# Shuttle Program

## Formulation, Development and Operations

Master Forum # 19
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# Space Shuttle
# A Real Experience and Great Machine

# Introduction

- Panel members
  - Tom Moser – Program Mgt. and Orbiter Dev.
  - Jody Singer – Propulsion Systems Dev.
  - Russell Rhodes – Launch Ops.
  - John O’Neil – Mission Ops.
- We have a lot to share and a little time
  - 30 minutes for each to speak
  - 15 minute Q&A for each segment

# Passing the Torch
# **Five Lessons Learned**

- “Political Systems Engineering” has and will continue to increase.
- Freeze the configuration but not the program plan
- Simple system interfaces simplify program management and reduce risk
- “Better is the enemy of good”
- Operational flexibility cover development short falls.

# Program Management and Orbiter Development

- Transitioning from Apollo era to Shuttle era
  - Huge difference in technology challenges and the political environment
- Early Shuttle program formulation
  - Studied many options
  - Froze the configuration but not the development program
- Orbiter systems development
  - Simplify system interfaces
- Early operations
  - Operating to stay within the capabilities
  - Moving from development into operations

# Transitioning from Apollo Era to Shuttle Era

- Program management challenges were very different because of
  - The political environment
    - Bureaucracy and oversight increased
  - The technology requirements
    - Technology issues decreased
  - The need to keep the program “sold”
    - A new challenge

# Changes in the Political Environment

- Different political environment
  - Apollo – The Presidents program, full political support, money was not an issue, very little oversight, schedule driven.
  - Shuttle – “Sold” to the White House, fragmented political support, money was tight, schedule was a variable, more bureaucracy
  - Apollo program management could focus on
    - Organizing and managing the government and industry team
    - Developing technologies

# Technology Challenges

- Technology
  - Apollo – “We did not know what we did not know”, numerous and huge technology and ops challenges
  - Shuttle –Major developments
    - Propulsion systems
    - Thermal protection systems
    - Avionics
    - Reusability
  - Shuttle Program Management had to balance technology and “routine” ops challenges

# Continuously Selling the Program

- Keeping the program “sold”
  - Apollo – Not an issue
    - An excited public, Congress and White House
    - Many frequent events to show progress
  - Shuttle – A continuous challenge
    - Funding was tight and the mission objective was not as dramatic
    - Years of development with no “gee wiz” events until the Orbiter Approach and Landing Tests
      - The last two years the objective was to get the “SoB” in Space
  - Program Management had to re-plan schedule and content every year.
    - Increased communications up to keep the program sold and down because of a frustrated team

# Transitioning from Apollo era to Shuttle era

- There seems to be a “Conservation of program management complexity”
  - Apollo had extreme technical and management challenges but was simple politically.
  - Shuttle had fewer technical and management challenges but many political challenges.
- “Political Systems Engineering” became a new and required skill for Shuttle program management.

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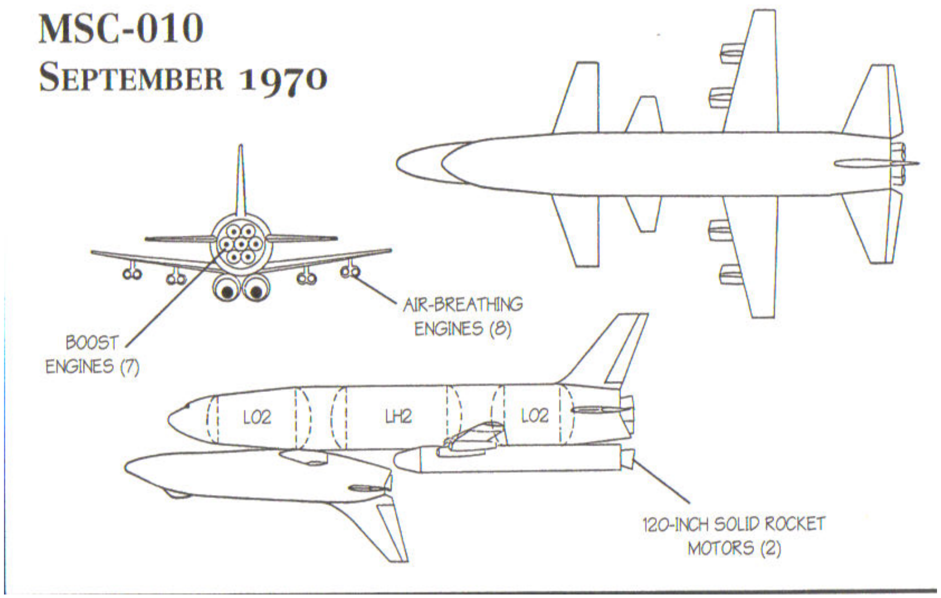
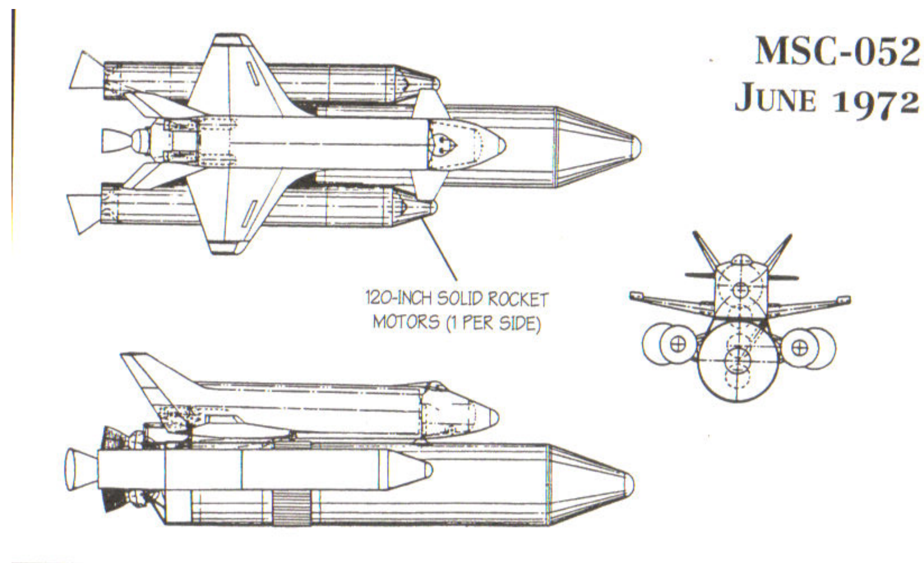
# Shuttle Program Design Variables

- Earth-to-Orbit Transportation System
- Multi-year budgets
- Development and ops costs
- Payload mass and size (delivery and return)
- Operational orbits
- Fully or partially reusable flight systems
- Turn-around time
- Entry cross-range

# Shuttle Configurations



# Early Shuttle program formulation

- Developing requirements and options
  - Phase A/B – Establish the configuration and top level requirements
  - Phase C/D – Establish the design details and derived requirements
- The balance was between development and operations costs
  - The program had to fit within the annual projects funds available
  - Operations costs suffered

# Early Shuttle program development

- The Baseline Design did not change
  - The development of the four Shuttle flight elements proceeded in parallel
  - The Orbiter was developed for the original costs estimate of $5 billion because
    - Many and continuous changes were proposed but denied
    - Some subsystems were changed to “make work” and reduce weight and costs, but with no impact on other subsystems
- Orbiter Project management philosophy:
  - “Better is the enemy of good”
  - “The most innocuous change is the most far reaching”

# Managing the Program by Changing Plans not Configuration

- The Orbiter certification plan evolved to accommodate budget reductions
  - Full-up systems Thermal Vacuum tests of the forward and aft fuselage eliminated
    - Component TV tests performed
    - Full system analyses performed
    - Early flights designed to be benign, verify analyses, and gradually “open the envelope”
  - Two Orbiter airframes for strength and life verification were eliminated
    - The *Challenger* airframe was tested to 120% of mechanical design loads and later used as a fight vehicle
    - Structural analytical models were verified
    - Thermal “loads” were added analytically
    - Smaller acoustic fatigue tests were conducted for life certification
  - Flight certification and safety were never compromised

# Structural Test Article- *Challenger*

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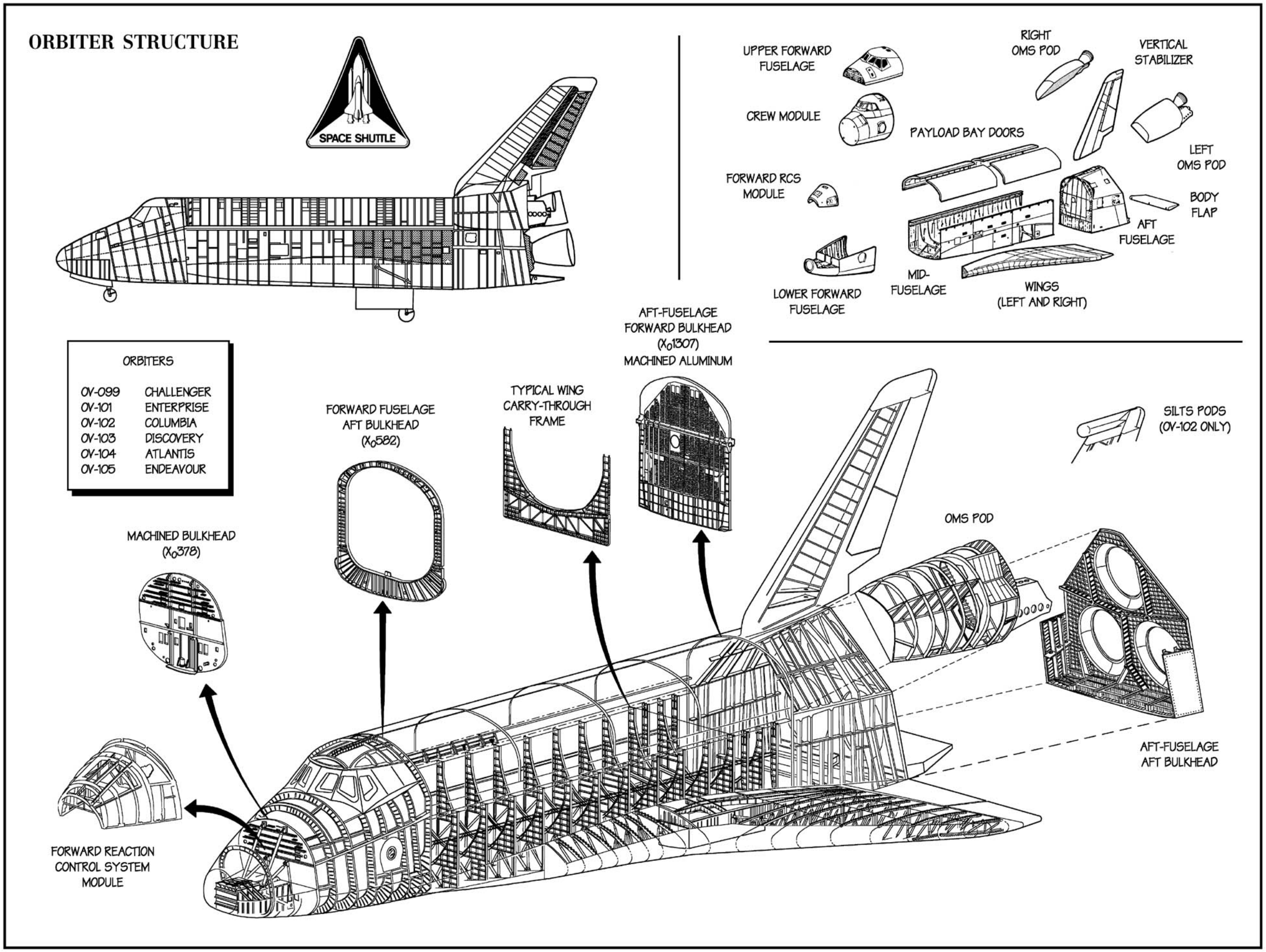
# Orbiter Development

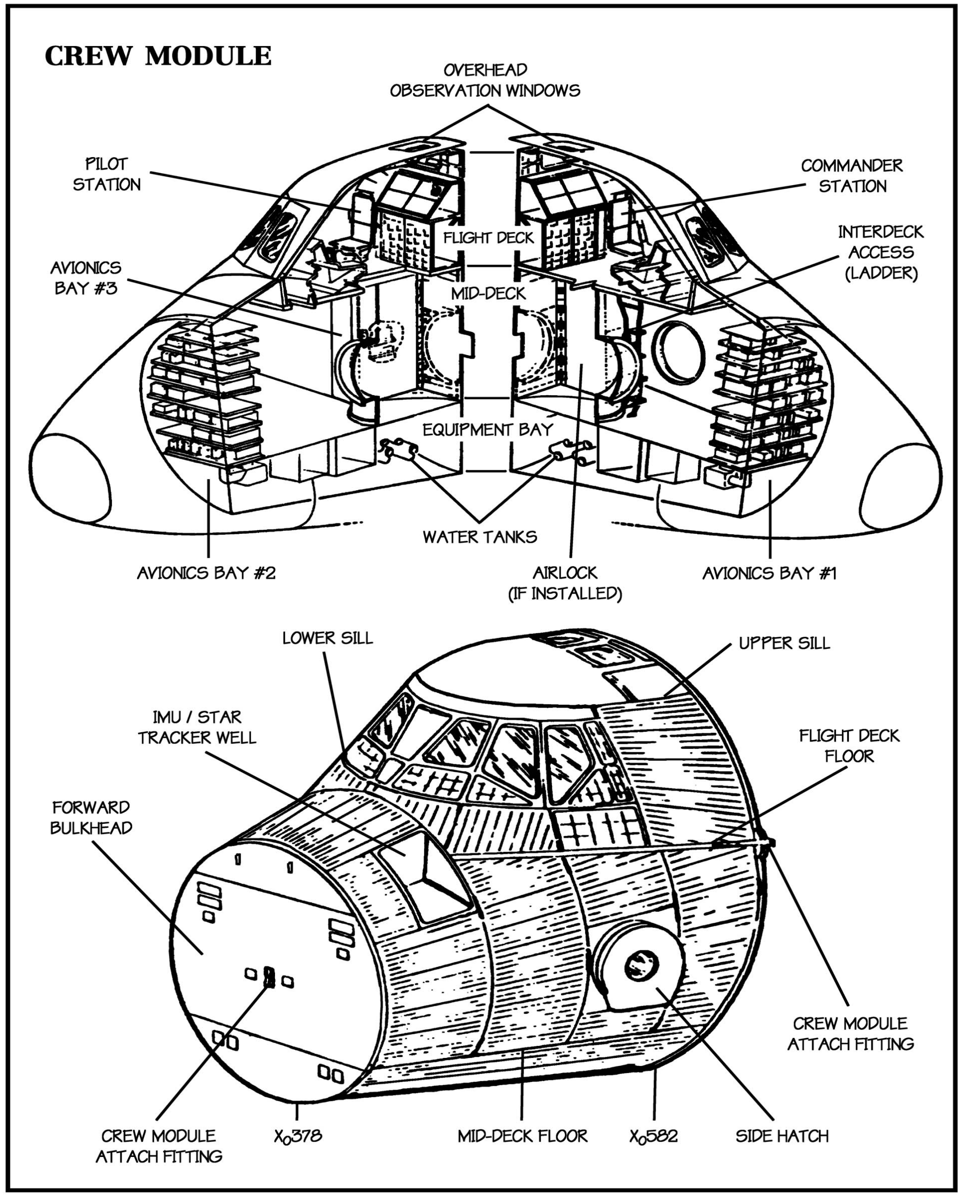
- Simple Structural Interfaces
  - Payloads in the Orbiter payload bay
    - Decoupled the structural design of the Orbiter and the Payload by having a “statically determinant” attachments
    - Moveable attachments enabled a combination of 10 million payload elements, sizes, masses, and C.G. locations
  - Crew Cabin in the Forward Fuselage
    - The CC was designed to “float” in the fuselage
    - This simplified the design of the crew cabin to that of a pressure vessel and increased the reliability with pressure tests.
- Simple interfaces and parallel development reduced program management complexity

# Structure Configuration

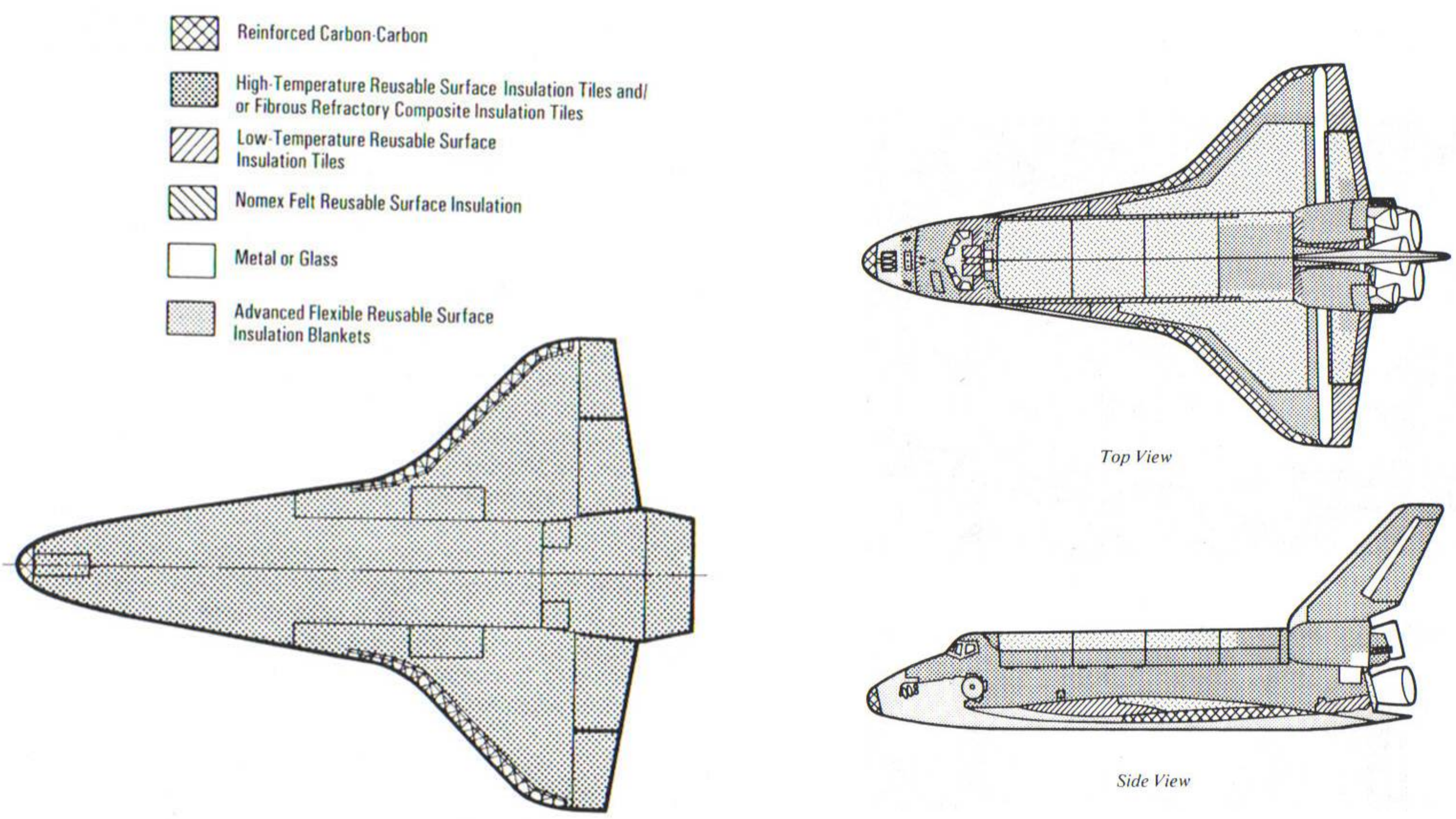


# Crew Cabin in Fuselage
## (Simple Interface)

- Pressure vessel design
- Four discrete attachment points with the forward fuselage
- Minimum heat transfer to Crew Module
- Fracture mechanics – leak before rupture



# Orbiter Thermal Protection System



# Tile to Structure Interface

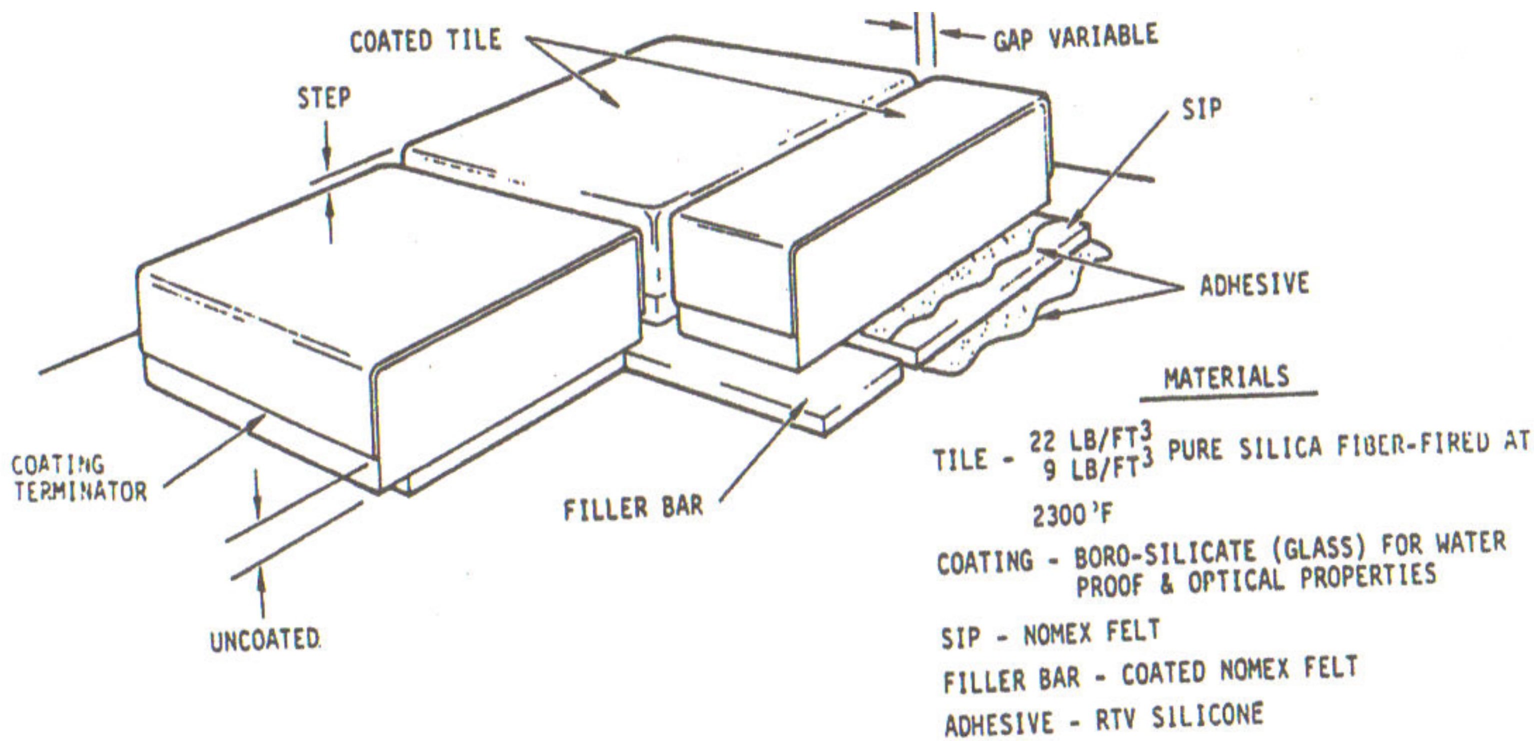



Figure 7.- Tile design.

# Complex Interface
# Big Program Management Issue

Structural Deformation

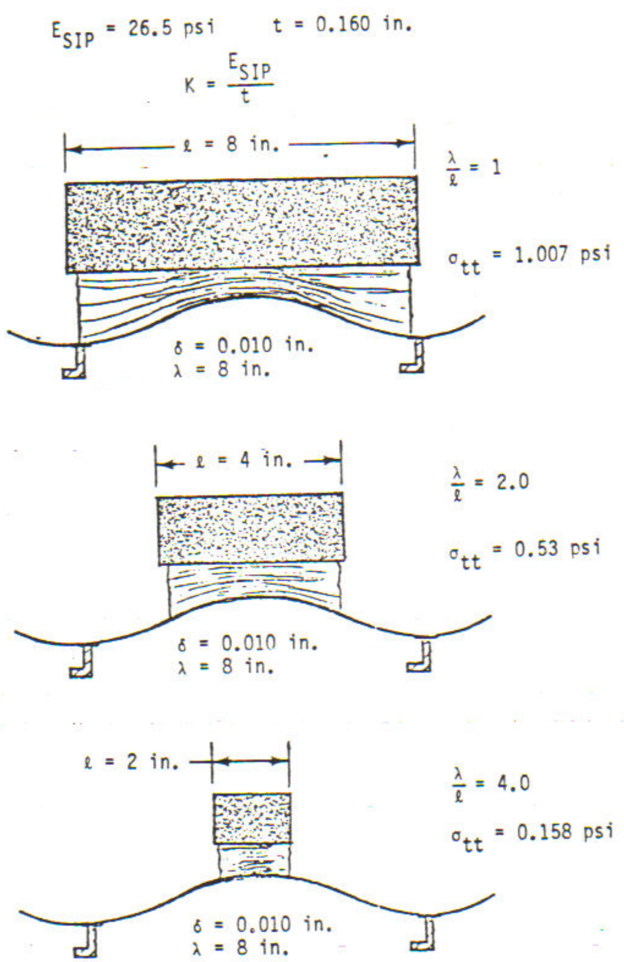



Fig. 6 Effects of substrate deflection.

Pressure Distribution

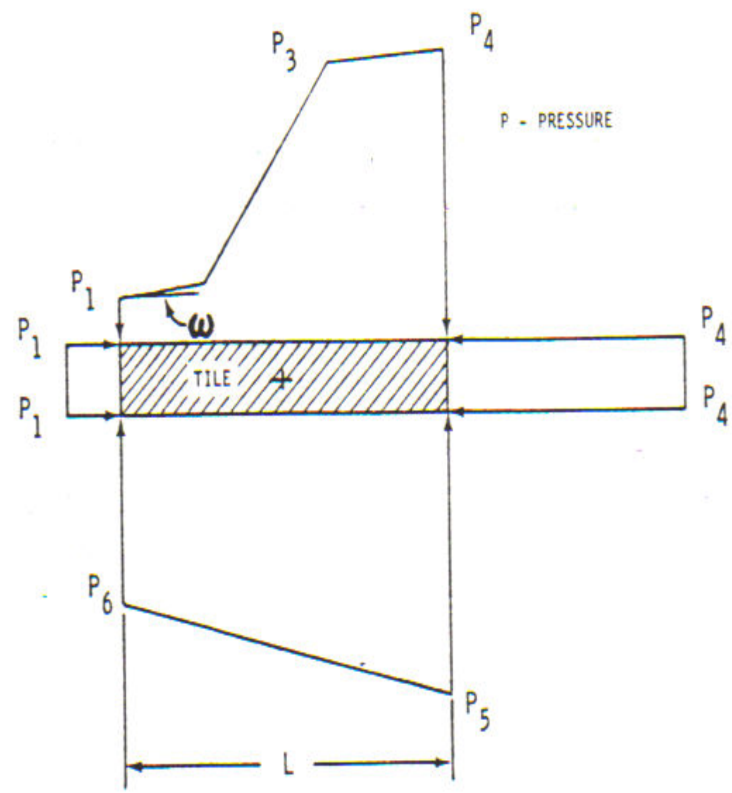



Fig. 7 Aeroshock freebody model for air loads.

# Orbiter Lesson Learned

- Simple interfaces simplify program management
  - Orbiter to ET
  - Payload to Orbiter
  - Crew Cabin to Fuselage
  - TPS tiles to Orbiter

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# Wing Load Surprise on STS-1

- Wing loading during ascent was greater than expected
  - The center of aerodynamic pressure was further aft and outboard
- How to proceed?
  - Placard ascent flight parameters to stay within the structural capabilities of the wings.
- Lesson learned:  Ops guys sometimes have to save the development guys’ A - -.

# Fuel Cell Surprise on STS -2

- Problem: Debris clogged the line, shut down one of three fuel cells, and terminated the mission early.
- Fix: Put a debris filter in the line.
- Better fix: Put in two debris filters.
- Wrong: Hydrogen gas was trapped between the two filters and injected into the reservoir. We had a potential bomb on the Orbiter.
- Lesson learned: One filter was good. Stick with the principle that “Better is the enemy of good”.

# Planning for Spares

- A new challenge for Shuttle management:
  - Planning and providing operational spares for a reusable fleet of vehicles
  - Primarily determining the failure rate, warehousing, and funding.
  - Early Shuttle flights had to obtain spares from cannibalizing vehicles on the assembly line
- Lessons learned: Logistics is not “sexy”, but it is necessary for efficient operations.

# Spares for Facilities in Space

- A large Systems Engineering challenge
  - If the facility  is to be “available” for operations 90% of the time
  - Every operating system, subsystem, or component has to be “system engineered” to be compatible with
    - Limited storage of spares at the facility
    - Limited crew time for repairs
    - Limited transportation to the facility
- Lesson learned:
  - Establish the “availability” requirements for every “black box”
  - Determine the optimum solution of how many spares, where to store, maintenance manpower, and costs.

# Shuttle "Ham & Eggs Society"

A successful Program Manager needs a fully committed team.

# Space Station

- To date this has been the ultimate in changes required for the program to be successful
- Everything has changed
  - Program Management
  - Baseline configuration
  - Program partnership
  - Budgets and Schedules
  - Logistics